How much does the migration aperture actually contribute to the migration result?

Shuang Sun and John C. Bancroft

ABSTRACT

Reflection energy from a linear reflector comes from the integrant over an aperture, often described by the Fresnel zone. Within the Fresnel zone, the diffraction energy constructively builds the reflection energy. To get true reflection amplitude, a migration aperture that is twice the Fresnel zone size must be considered. This paper derives the size of the prestack Fresnel zone as a function of half the source-receiver offset. It evaluates how the size of the migration aperture affects the migration result, then establishes an acceptable minimum migration aperture for horizontal reflectors. For both zero-offset and offset data, twice the Fresnel zone size is the minimum migration aperture to preserve true amplitude. A migration aperture that is larger does not improve the migration result.

INTRODUCTION

A Fresnel zone is defined as the intercept when a spherical wave penetrates a plane to a depth of half a wavelength (Claerbout, 1985). The Fresnel zone identifies the area that contributes energy to a migrated trace and is shown in Figure 1. The migration aperture in Kirchhoff summation method must be larger than the Fresnel-zone size to get the true reflection amplitude. It is worthwhile to investigate the relationship between the prestack Fresnel-zone size and the prestack migration aperture, to maximize the signal and minimize the noise. It is also necessary to establish a minimum aperture to preserve the true amplitude.

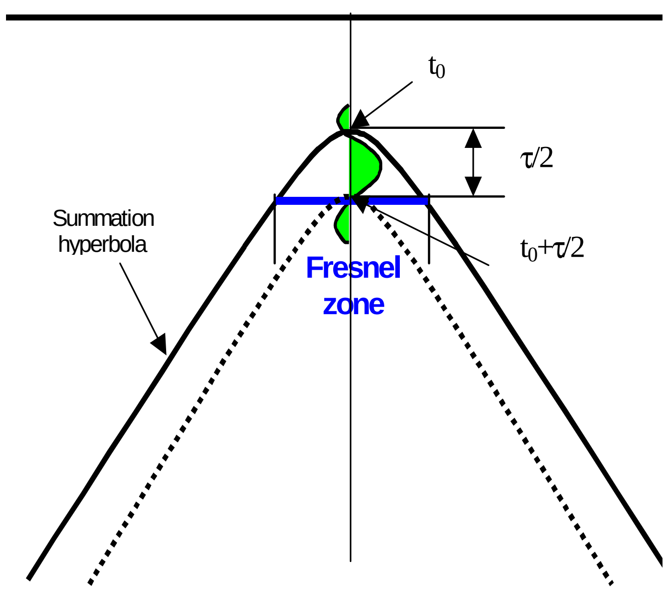


FIG. 1. Fresnel zone for zero-offset section.

Sun (1998) concluded that the minimum migration aperture should be the interval where the difference between the traveltimes of reflected and point-diffracted rays equals the duration of the recorded seismic pulse. He showed zero-offset numerical examples to confirm his results. Sun's minimum migration aperture is twice the Fresnel zone size definition. In this paper, numerical examples show that the minimum migration aperture using twice the Fresnel-zone size also guarantees the prestack migration results in an offset section.

OFFSET AND FRESNEL ZONE

For prestack migration the Kirchhoff summation traveltime curve in an offset section is determined by the double-square-root (DSR) equation as:

$$t=\sqrt{\frac{t_0^2}{4}+\frac{(x+h)^2}{v^2}}+\sqrt{\frac{t_0^2}{4}+\frac{(x-h)^2}{v^2}}, \tag{1}$$

where h is half the source-receiver offset, t_0 is two-way vertical traveltime, v is RMS velocity at the scatterpoint, and x is the surface distance between the midpoint and the scatterpoint.

For a horizontal reflector, according to Claerbout's definition mentioned above, we derived the Fresnel zone size as a function of half source-receiver offset in an offset section using DSR equation.

The DSR equation can be rewritten as:

$$t^2=t_0^2+\frac{4(x^2+h^2-\frac{4x^2h^2}{v^2t^2})}{v^2} \tag{2}$$

From Figure 2, we included the offset Fresnel-zone displacement x_f using equation (2) as:

$$(t_h+\frac{\tau}{2})^2=(\sqrt{t_0^2+\frac{4h^2}{v^2}}+\frac{\tau}{2})^2=t_0^2+\frac{4(x_f^2+h^2-\frac{4x_f^2h^2}{v^2t_h^2})}{v^2} \tag{3}$$

where t_h is the traveltime at the given half-offset h, and τ is the period of the wavelet. We can solve for the Fresnel zone radius x_f, giving:

$$x_f = \sqrt{\frac{\tau v^2 \sqrt{t_0^2 + \frac{4h^2}{v^2}}}{4 - \frac{h^2}{v^2 t_0^2 + 4h^2}}} \tag{4}$$

For zero-offset, i.e. *h*=0, the Fresnel zone radius is exactly the same as Sheriff's (1980) definition:

$$x_f = \frac{v}{2}\sqrt{t_0 \tau} \tag{5}$$

The summation curve and the Fresnel zone in an offset section are shown in Figure 2.

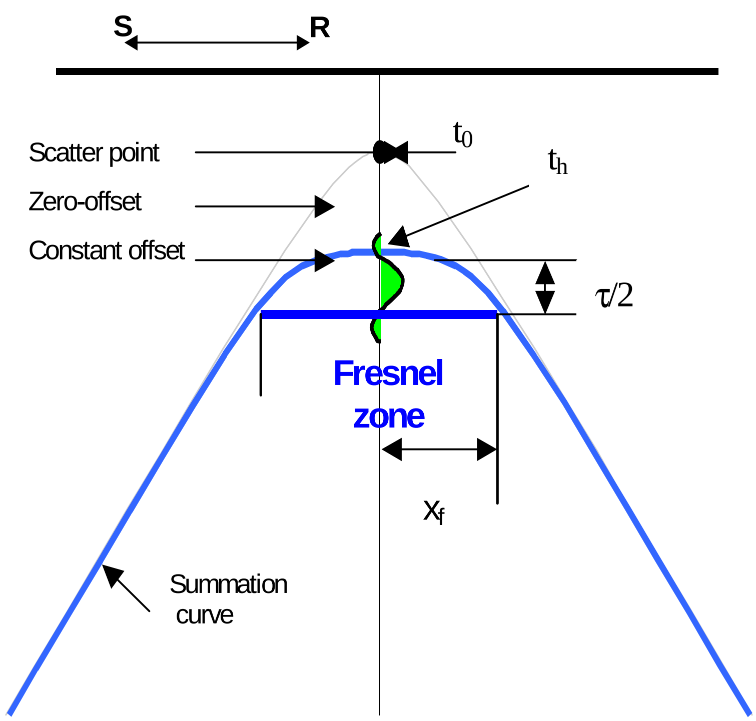


FIG. 2. Fresnel zone for offset section.

Assuming no frequency decay in the source wavelet, the variation of the Fresnel zone radius, verses the half source-receiver offset for horizontal reflector, is shown in Figure 3. As the Fresnel zone radius increases with half source-receiver offset, the migration aperture should also increase with half source-receiver offset.

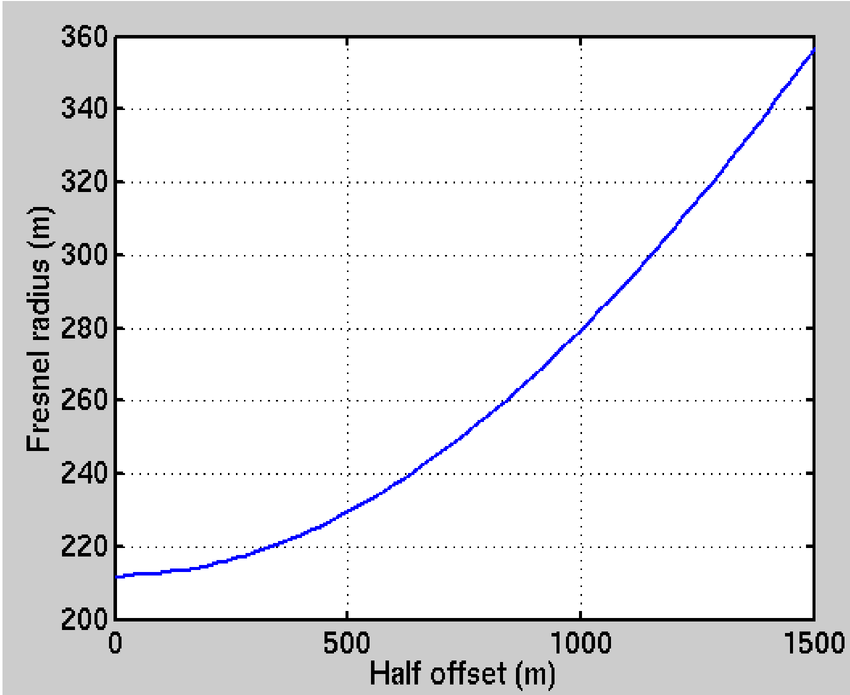
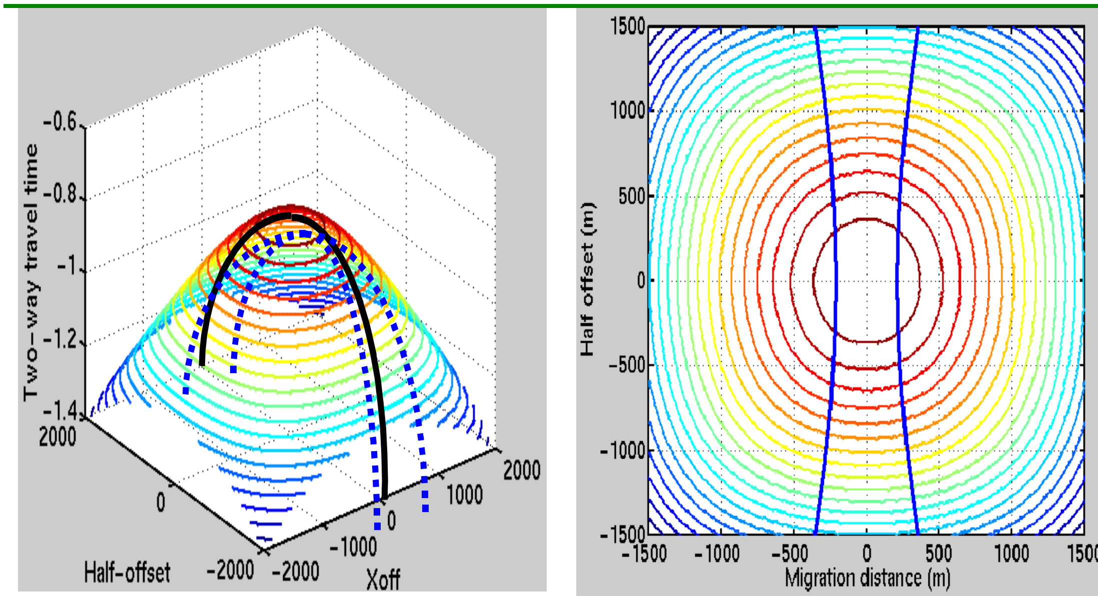


FIG. 3. Fresnel zone radius varies with half source-receiver offset.

FRESNEL ZONE IN CHEOPS PYRAMID

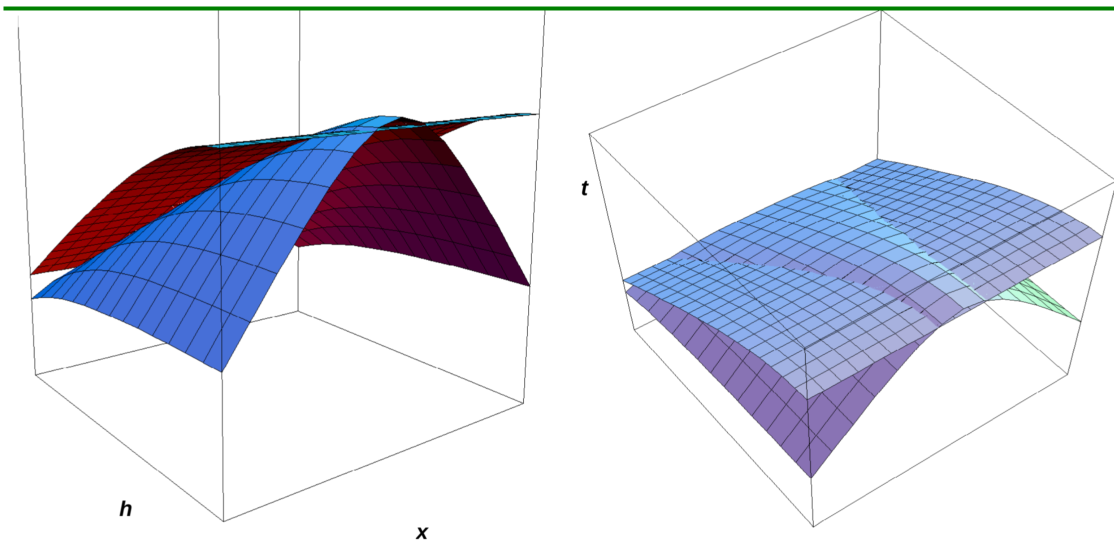
In the pre-stack volume (*x*, *h*, *t*) the DSR equation describes the traveltime from a scatterpoint as a surface that is referred to as Cheops pyramid (Claerbout, 1985). To migrate energy back to a scatterpoint, the prestack migration sums all the energy along the Cheops pyramid. However the reflection energy, i.e. the ‘specular’ energy from a linear reflector, comes from an area proportional to the size of the Fresnel zone. For horizontal reflector the high-frequency ‘specular’ energy of the scatterpoint forms a hyperbola as shown in Figure 4a by a solid curve. The dashed lines show the band-limited Fresnel zone as a function of the half source-receiver offset in Cheops pyramid. The offset Fresnel zone can be seen more clearly by the contours in the plan-view of the Cheops pyramid as shown in Figure 4b.



(a) (b)

FIG. 4. Specular energy and Fresnel zone of a horizontal reflector in a) Cheops pyramid in (*x, h, t)*, and b) contours of Cheops pyramid in (*x, h)*.

The shape of the Fresnel zone can also be illustrated by the intersection of Cheops pyramid and the prestack surface of a horizontal reflector: a hyperbolic cylinder. Raising the Cheops pyramid by half period $\tau/2$ produces an intersection that maps the Fresnel zone as illustrated in Figure 5. The front view is shown in (a) and a view from above is shown in (b).



(a) (b)

FIG. 5. Prestack Fresnel zone for a horizontal reflector defined by intersecting the hyperbolic cylinder with Cheops pyramid, a) frontal view and b) from above.

FRESNEL ZONE AND MINIMUM MIGRATION APERTURE

Migration is used not only for structure correction but also for estimating the true reflection amplitude. To get the true reflection amplitude, both the migration aperture and its location are the determinate factors. However for a horizontal reflector, the tangent point, i.e. the reflection point, is the same point as the scatterpoint. In this case the migration aperture is centred at the scatterpoint. For a dipping reflector, the tangent point on the diffraction curve identifies the migration aperture.

What is the minimum migration aperture really needed to migrate a point to get the true reflection amplitude? Traditionally we use a migration aperture that is as large as possible, assuming it can get the best migration result. In fact the migration aperture need not to be so large to get the reflection amplitude from linear reflector. In some cases the minimum migration aperture should guarantee the true reflection amplitude. A larger migration aperture has no improvement on the migration result (for a linear reflector). Numerical examples show the minimum prestack migration aperture, to preserve the true amplitude, should be twice the size of the Fresnel zone defined in the above sections.

NUMERICAL EXAMPLES

For a simple case we test the migration aperture assuming that there is only two interfaces in the subsurface which has an AVO effect. The middle layer is with some gas in it. Figure 6 shows the velocity and Poisson's ratio of model. Assuming an incident plane wave, we use Zoeppritz equation to calculate the reflection coefficient and the phase of the reflected signal. Tests confirm that the minimum migration aperture for zero-offset migration and the constant offset migration should be the double size of Fresnel zone size.

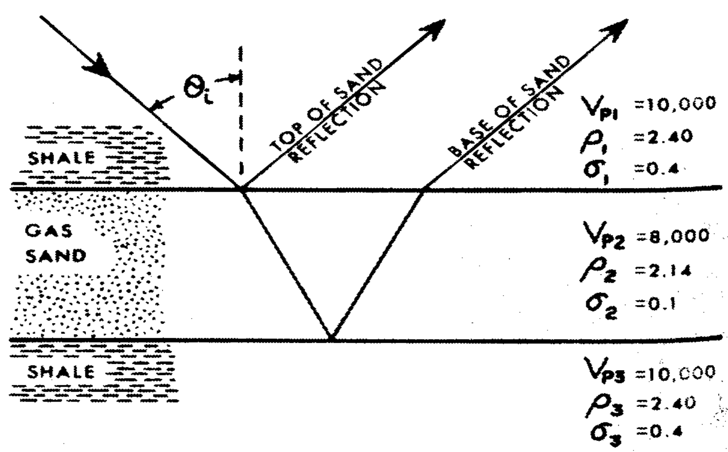
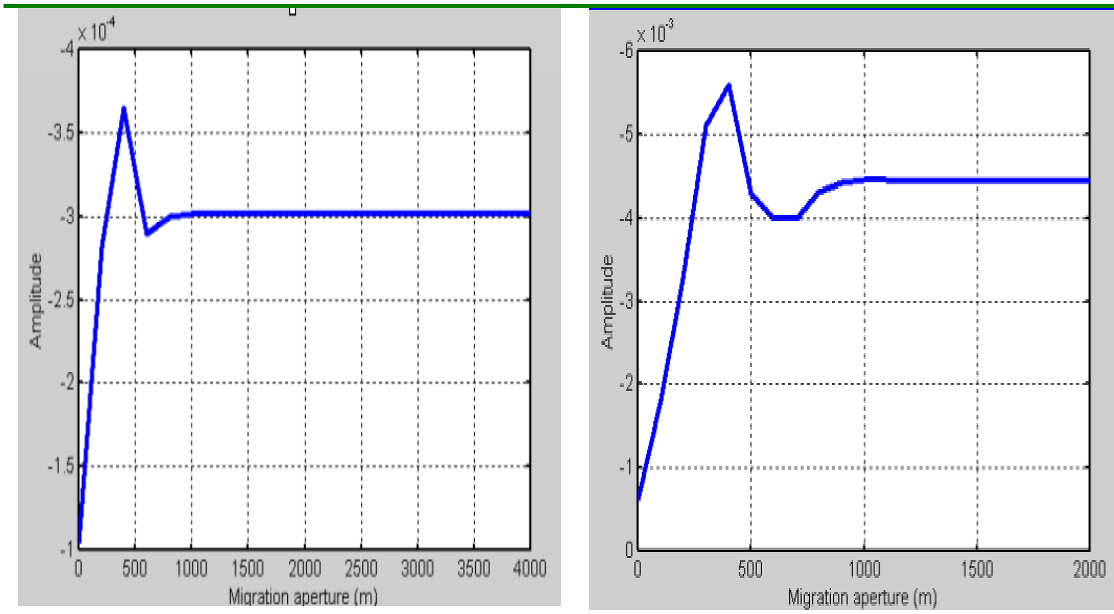


FIG. 6. Two-dimensional geology model used in the numerical example.

Results of upper layer

The following three figures show how the migration aperture contributes to the migration result. The amplitude first goes up to its peak then goes down and stabilizes.

Notice the stable point: as Figure 8 shows, the migration aperture at the stable point is just double the size of the Fresnel zone.



(a) (b)

FIG. 7. Migration aperture relates to Fresnel zone of upper layer. a) Zero-offset; b) Half-offset equals 500m.

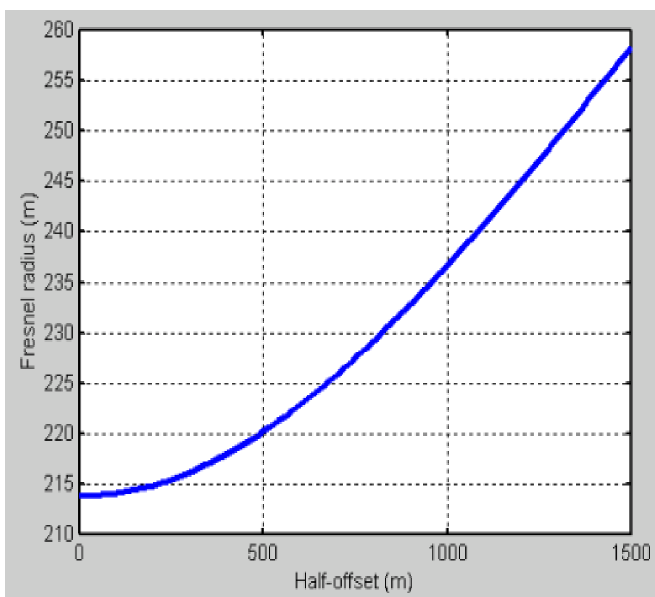


FIG. 8. Fresnel radius varies with half-offset of upper layer.

Results of lower layer

The following three figures show how the migration aperture contributes to the migration result. Again, for the lower layer, the amplitude also goes up to its peak then goes down and stabilizes. Notice the stable point: as Figure 10 shows, the migration aperture at the stable point is just double the size of Fresnel zone.

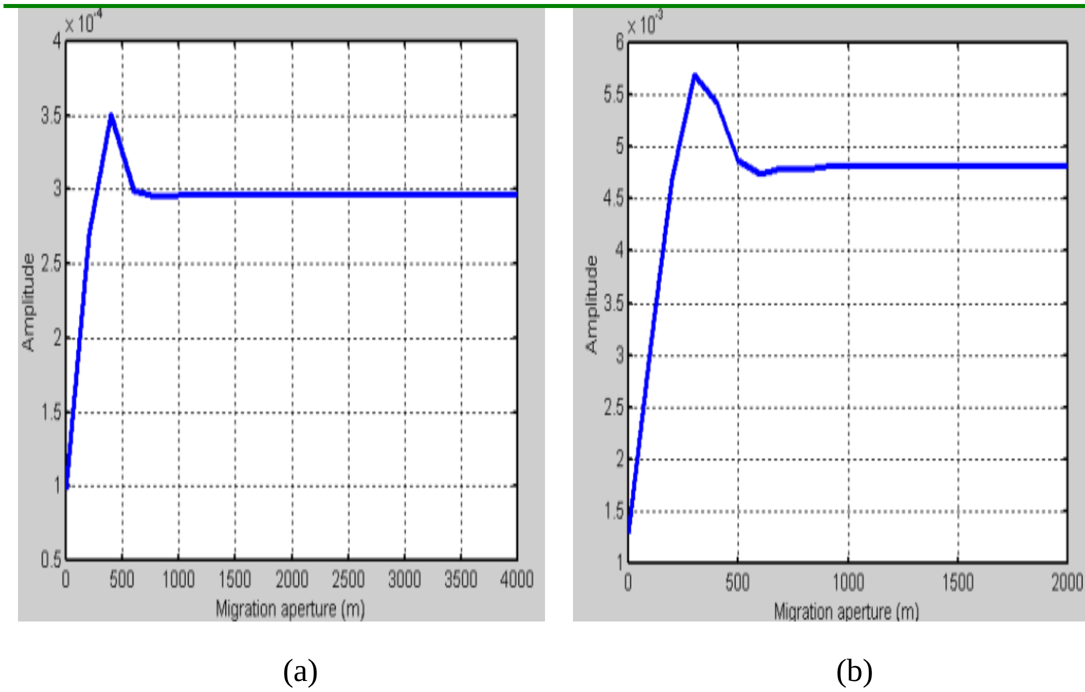


FIG. 9. Migration aperture relates to Fresnel zone of lower layer. a) Zero-offset; b) Half-offset equals 500m.

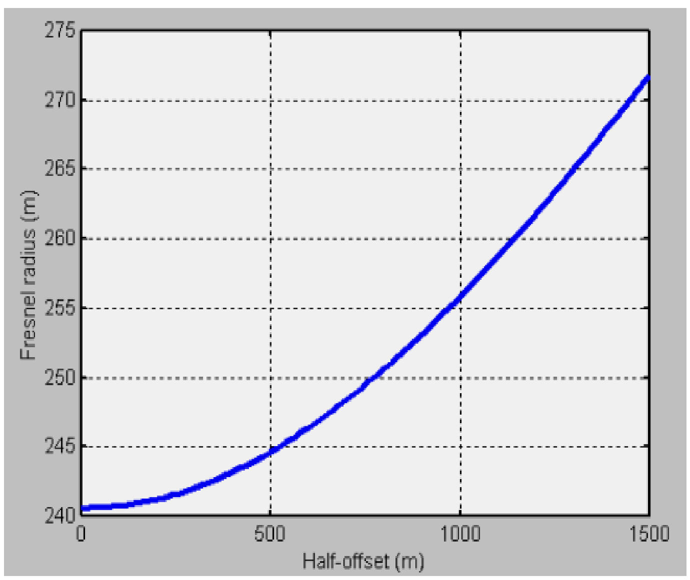


FIG. 10. Fresnel radius varies with half-offset of lower layer

CONCLUSIONS

The Fresnel zone for prestack data was defined to aid in identifying the prestack migration aperture.

To get true reflection amplitude, the minimum prestack migration aperture should be the twice of the Fresnel zone size in both the zero-offset section and the offset section.

A smaller prestack migration aperture that equals the size of the Fresnel zone may produce a satisfactory image.

ACKNOWLEDGEMENTS

We thank the sponsors of the CREWES project and NSERC for supporting this research.

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